National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Optical System Science and Technology; Computational Challenges and Development

ESTC 2006

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Outline

- Introduction: Motivation and Challenges
- Solution Approach and Enabling Technologies
- Development Effort Status
- Examples
- Summary

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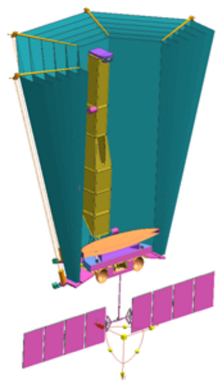
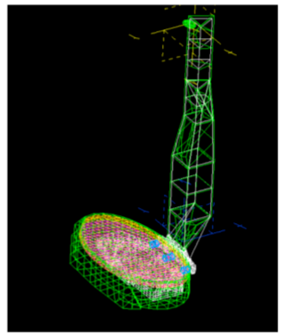
Introduction

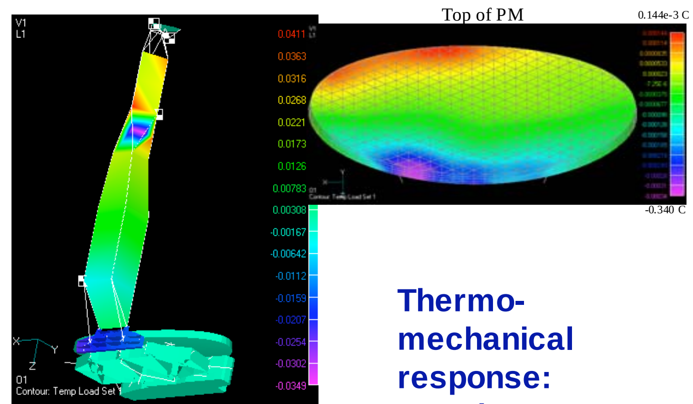
Case Study: Terrestrial Planet Finder – Coronagraph; 20° Dither Analysis



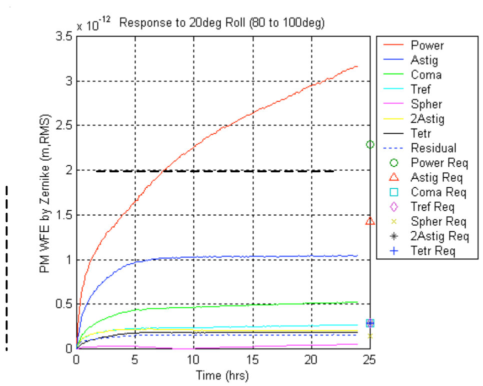
CAD model



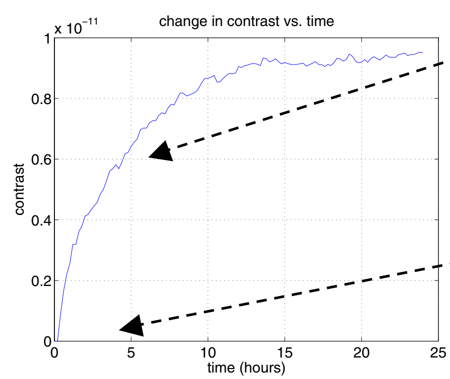
Analysis model: Thermal, mechanical, optical (common mesh)



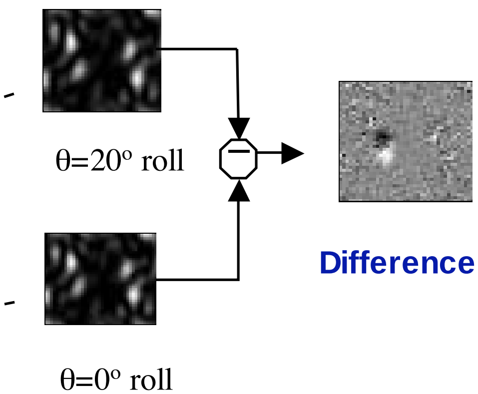
Thermo-mechanical response: Steady-state & transient



Transient WFE decomposed into 15 Zernikes vs. Reqmts.



Transient Contrast after 20deg dither



Difference

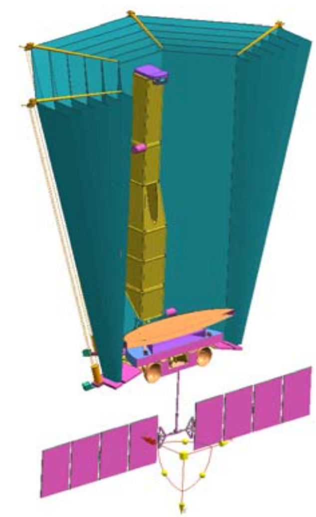
Speckle Removal for Planet Detection

Introduction

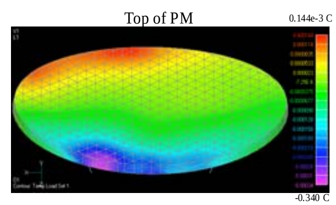
Large Aperture Multi-Scale Issues:

Long duration events requiring implicit solvers

System Level
Thermal-Structural-Optical Aberrations
Stability, Performance, System Control,
Design Optimization



Component Level
Thermal-Structural-Optical-Control
Nonlinear Continuum Mechanics



Test Correlation with
Data Acquisition and
Code Validation with
Experiments

Molecular Level
Nanoscale
Material Models,
Micro-Dynamics
Photon Effects,
Nanolayers,
Friction

Conversion of Microscale
Mechanics Tests & Simulations
into Continuum Mechanics
Models

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Solution Approach

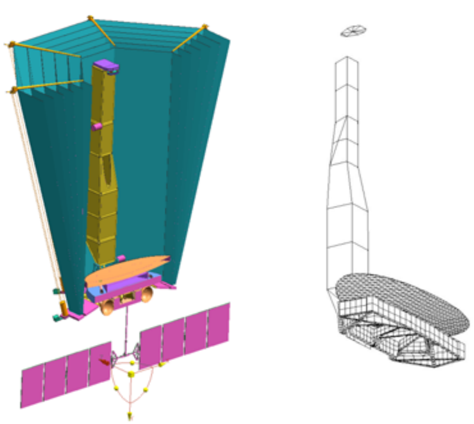
Description

- Development of advanced capabilities for the analysis-driven design of large aperture deployable systems

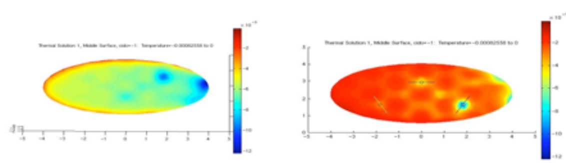
Objectives

- Enable “integrated modeling” by providing fundamentally-integrated thermal, structural, and optical aberration analytic capabilities. General purpose
- Implement computationally efficient methodologies for analysis and design optimization study purposes
- Provide an object-based, extensible platform for advanced methods development and research
- Deploy process improvement to organization and to projects (including benchmarking, documentation, and support)

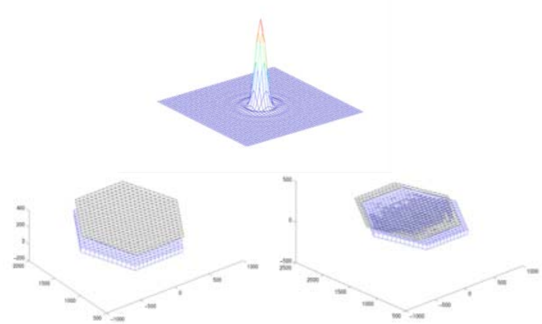
Integrated analysis capability facilitates development of detailed system-level model …



Propagates thermal, structural & dynamic effects down to optical elements and mounts …



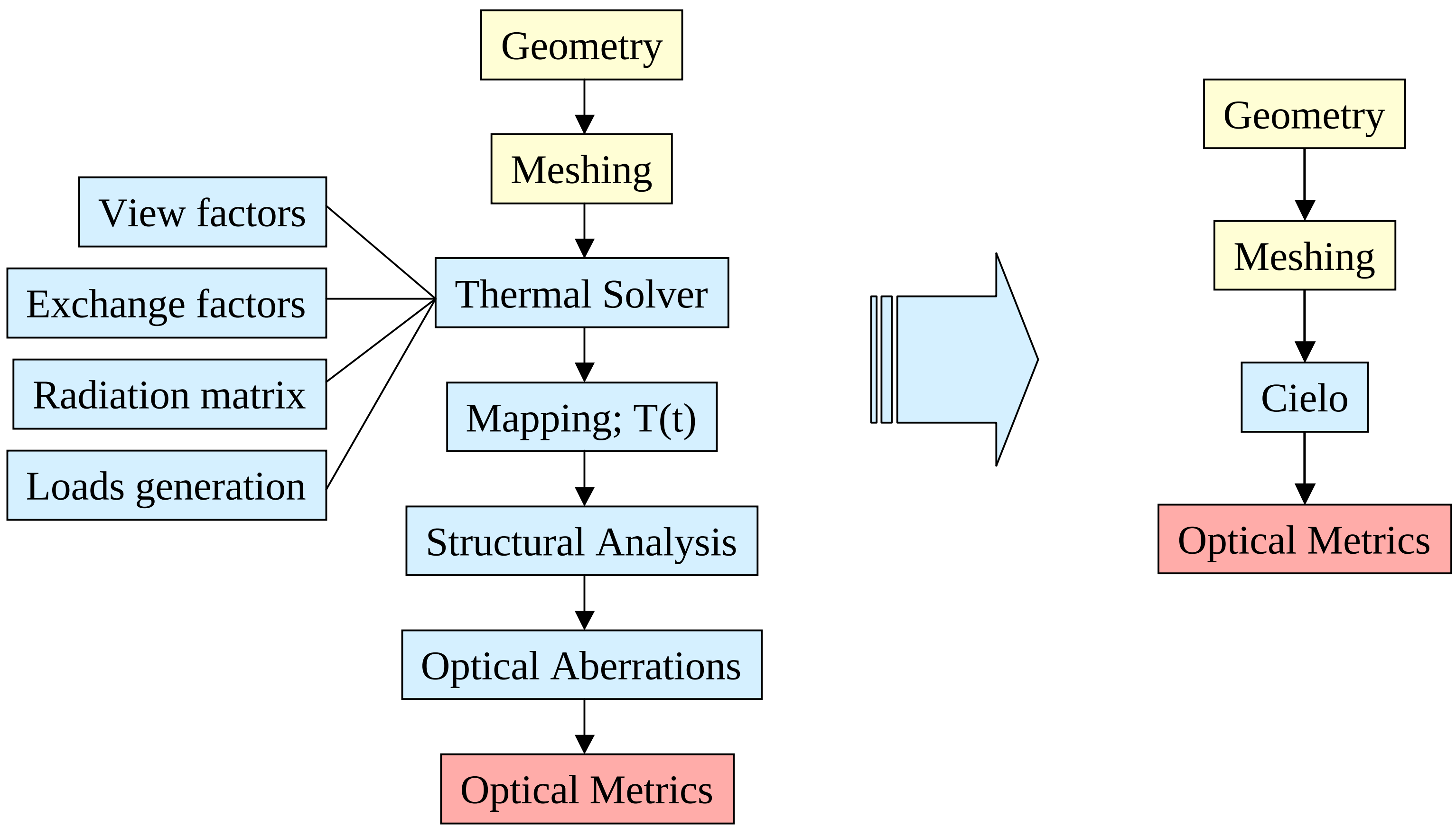
And computes aberrations from which optical merit functions & sensitivity matrices can be assessed and optimized…



Solution Approach

“STOP” Analysis:

“Go” Analysis:



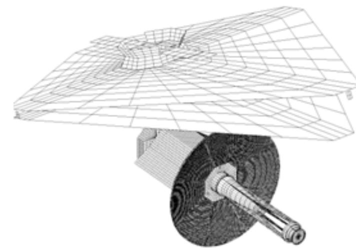
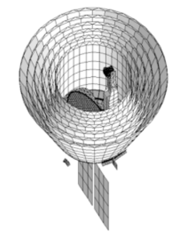
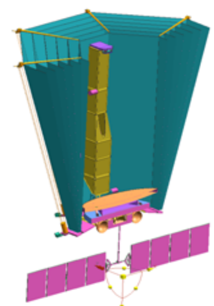
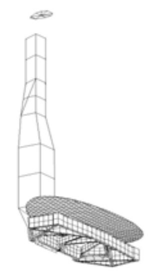
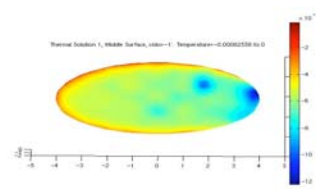
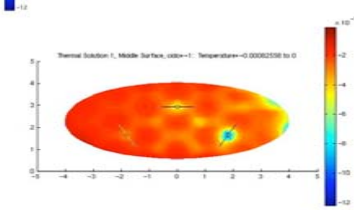
Integrated Toolset Status – Where are we Today?

In Practical Terms:

- Model pre-processing
  - Data handling for 500,000+ dof contractor-supplied Nastran input files (JWST, SIM)
  - Benchmarks to date of >1.2M dof
  - Object-based data schema, code architecture, are fully scalable and extremely robust
  - Models can have thermal, structural, and optical attributes

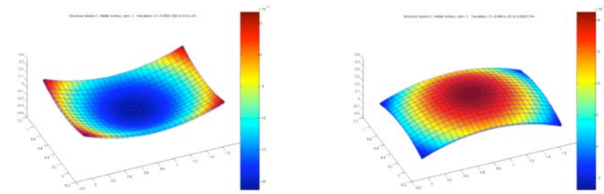
- Nonlinear transient thermal analyses
  - 5000 dof TPF model under 30 degree rotation in orbit; diffuse exchange, conductance, capacitance, adaptive in time, parallel computing
  - Code stability benchmarking to ~1k time steps

- Other steady state thermal analyses
  - Controlled mirrors of 10,000 dof, TPF-C primary mirror, deployable antennae composite panels

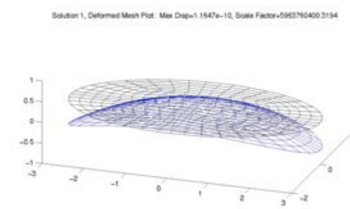







Status (cont.)

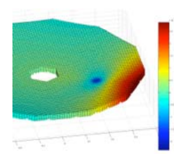
- Thermal deformation (static structural analysis)
  - Controlled mirrors, deployable panels (including Matlab-based HDF5 results output for radar code integration)

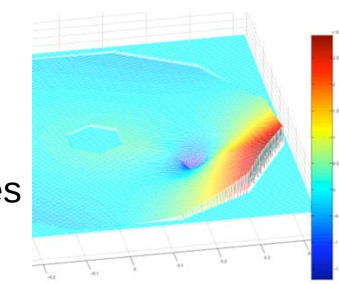


- Normal modes analysis in structural dynamics
  - Benchmarking of 300,000 dof plate model
  - TPF-C mid-fidelity primary mirror

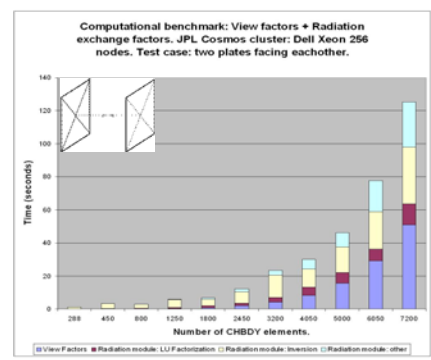


- Optical Aberrations
  - Mirror influence functions
  - Several hundred actuators as individual subcases





- Parallel Computing
  - Leveraging JPL's cosmos cluster (Dell xeon, 1024 nodes) for parallel nonlinear transient/steady-state heat transfer with radiation exchange



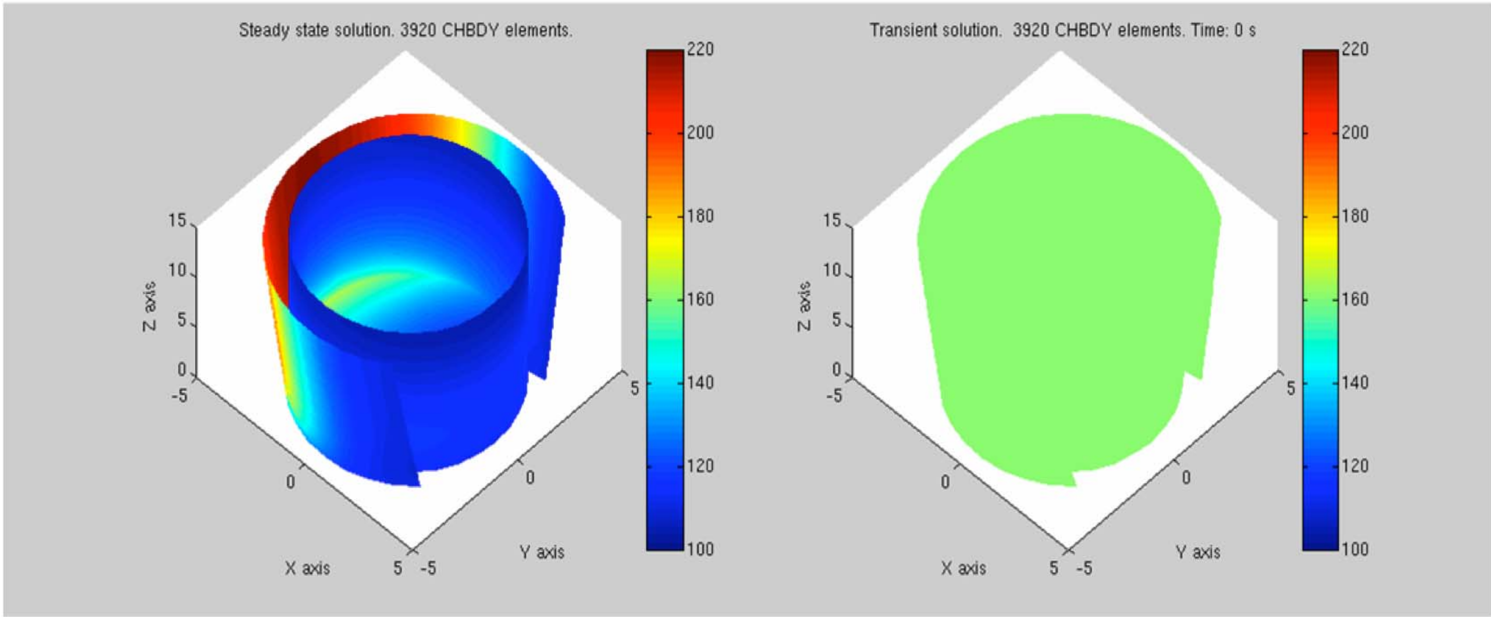
Example: Sunshade Thermal Analysis

TPF-C alternative sunshade study

- 3920 heat transfer surface, 3920 structural elements
  - 3 exchange cavities
  - solar loading, view of space

Steady-State Solution
• 10 iterations

Transient Solution
• 200 adaptive time steps from 0 to 11,560 sec
• 2-3 nonlinear iterations per time step
• 256 processors, ~40 min. run time

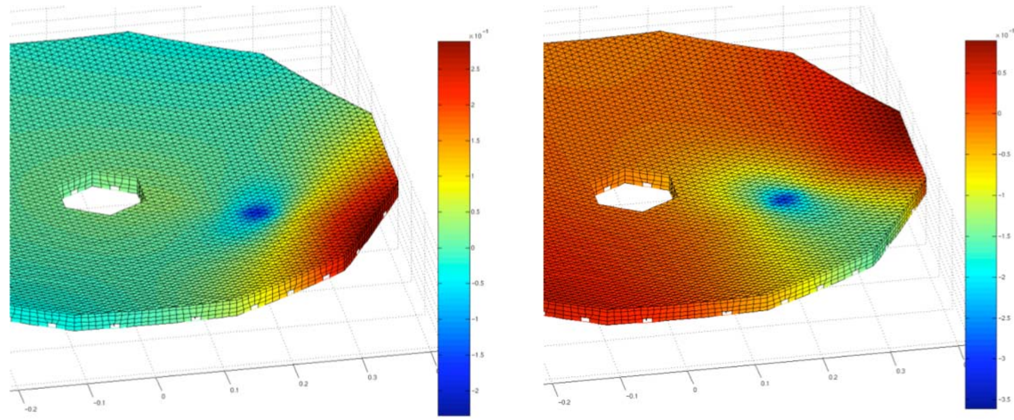


Example: Precision Optical Responses

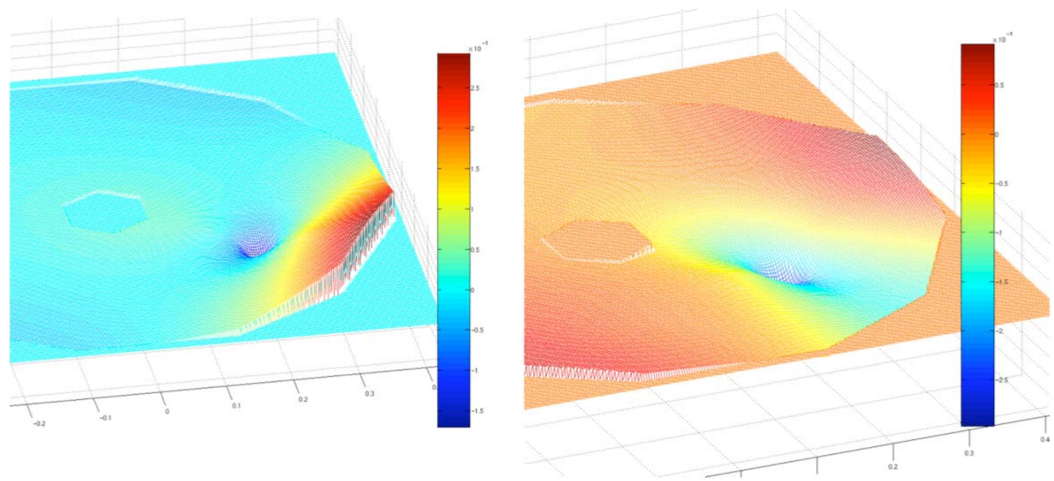
Optical Aberrations:

- Resulting from thermally-induced (or other) deformations, for any number of optical elements, coordinate systems, analysis subcases
- Provides much-anticipated interface to MACOS, other internal/ external codes
- Computed axially in optical element coordinate system, on n_y x m_x grid, and output in interferogram file format
- Fully data-driven, integrated with other Nastran input conventions
- Use as a basis for wavefront error, other optical metrics

Transverse displacement contour plots:



Corresponding aberrations, in interferogram format (256x256 grid):



Summary

Future precision deployable systems will be launched without benefit of full system ground-based testing

Operational scenarios, flight margins will be based in large part on confidence gained through simulation

Precision, optimality, correlation requirements are clearly driving finite element-based computational state of the art

Though significant progress has been made, much remains; recognize we’re on the steep part of the learning curve!